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Compact Environmental Anomaly Sensor (CEASE) Flight Integration Support Contract

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13. ABSTRACT *(Maximum 200 words)*

The outer space environment experienced by modern, electronically sophisticated spacecraft can be very hostile due to interactions between complex, sensitive electronics systems and the naturally occurring energetic particle population indiginous to the solar system. The Compact Environmental Anomaly System (CEASE) has been developed as a small, low-power device to monitor space "weather" and to provide autonomous warnings of conditions that may cause operational anomalies in the host spacecraft. CEASE uses a two-element, solid-state telescope and two radiation dosimeters to sample critical energetic particle fluxes and uses a sophisiticated real-time processing program that can forecast hazardous conditions before they affect the spacecraft. The spacecraft, in turn, can re-prioritize its operations, inhibit any anomaly sensitive operations such as attitude adjustments, or initiate other prudent actions as indicated by the CEASE warning flags.

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Compact Environmental Anomaly Sensor, CEASE, Surface Charging
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List of Acronyms

ADC	Analog-to-digital Converter
CEASE	Compact Environmental Anomaly Sensor
DBT	Detector Back Telescope
DD1	Dosimeter 1
DD2	Dosimeter 2
DERA	Defence Evaluation and Research Agency UK
DFT	Detector Front Telescope
DSP	Digital Signal Processing
EATP	Experiment Acceptance Test Plan
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMI	Engineering Mode Interval
GSFC	Goddard Space Flight Center
HILET	High Linear Energy Transfer
LB	Logic Box
LOLET	Low Linear Energy Transfer
LSB	Least Significant Bit
LSN	Least Significant Nibble
MSB	Most Significant Bit
MSN	Most Significant Nibble
OBDH	On-board Data Handling
OSC	Orbital Sciences Corporation
PCB	Printed Circuit Board
S/C	Spacecraft
SDI	Science Data Interval
SEU	Single Event Upset
S/N	Serial Number
SR	Status Register
STRV-1c	Space Test Research Vehicle 1c
TSX-5	Tri-Service Experiment 5
UK	United Kingdom
WDC	Deep Dielectric Charging WF
WDL	Deep Dielectric Charging Fluence WF
WF	Warning Flag
WHR	Heavy Shield Dose Rate WF
WLR	Light Shield dose Rate WF
WSC	Surface Dielectric Charging WF
WSE	Single Event Upset WF
WSL	Surface Dielectric Charging Fluence WF
WTD	Total Dose WF

1. INTRODUCTION

This contract supports the flight code development, functional testing, environmental testing, calibration and spacecraft integration of the Compact Environmental Anomaly Sensor (CEASE) S/N 001 and S/N 002 instruments, built by Amptek, Inc. for the Air Force Research Laboratory. Under this contract, Amptek is supporting the delivery and integration of two CEASE instruments – S/N 001 onto the Space Test Research Vehicle 1c (STRV-1c) spacecraft and S/N 002 onto the Tri-Service Experiment 5 (TSX-5) spacecraft. This report documents the work conducted by Amptek on these CEASE flight units and accompanying engineering unit for the period of 5/1/98 to 4/30/99.

The mechanical and electronic design of CEASE on a previous contract was driven by the requirements of small size, low power, high reliability and radiation hardness, to allow the incorporation of CEASE into virtually any spacecraft. CEASE's on-board intelligence permits long-term, unattended operation of the instrument, giving the spacecraft operator as much, or as little, information as needed. CEASE is a small, low power instrument that provides operators with fully processed, real time, *in situ* measurements and autonomously generated warnings of the space radiation environment threats. CEASE reports these threats to the host spacecraft:

- Ionizing radiation dose and dose rates
- Single event effects
- Surface and deep dielectric charging

The primary CEASE output to the spacecraft, updated once per minute, is a 10-byte *Engineering Data* packet quantifying the threat levels associated with those space environment hazards. Appropriate action may then be taken by the spacecraft or its operators to mitigate risk.

2. MEASURED THREATS

CEASE measures the environmental hazards with five radiation sensors: two dosimeters, a particle telescope, and a single event effect monitor. CEASE II contains an additional sensor, an electrostatic analyzer. CEASE processes the raw data from this sensor suite to provide real-time warnings to the spacecraft. Further details on CEASE, in particular with respect to the radiation sensors and on-board data processing, can be found in: Dichter, B.K, et. al., "Compact Environmental Anomaly Sensor (CEASE): A Novel Spacecraft Instrument for In-Situ Measurement of Environmental Conditions", *IEEE Trans. Nucl. Sci.*, Vol 45, No. 6, p. 2758, December 1998.

2.1 Radiation Dose

As electronic components are exposed to ionizing radiation dose, they suffer progressive cumulative damage. Once a threshold dose for a given component is exceeded, its performance will degrade and the component may even fail catastrophically. The failure mechanism can depend on the total radiation dose, the radiation dose rate, or the type of particles responsible for the dose. For example, some components are particularly sensitive to a displacement damage, a specific effect caused primarily by protons rather than electrons.

The particle populations primarily responsible for radiation dose damage are >5 MeV protons and >1 MeV electrons. To better assess the radiation dose threats due to these particles, CEASE distinguishes proton and electron dose effects. The conditions at geosynchronous altitudes and in high inclination orbits following a major solar flare and in the inner radiation belt present the most hazardous ionizing radiation doses for spacecraft.

CEASE measures *total radiation dose* (rads) and *dose rate* (rads/hr) with two independent dosimeters located behind planar aluminum (Al) shields. One shield is 0.08 inches (0.20 cm) thick and the other shield is 0.25 in (0.63 cm) thick. The smaller thickness represents a typical minimum shielding of spacecraft components (*Lightly Shielded Dose & Dose Rate*). The larger thickness is representative of well-shielded components (*Heavily Shielded Dose & Dose Rate*), since the dose-shielding depth curve changes slowly with shielding thickness above this value.

Radiation damage also dramatically compromises solar cell performance and lifetime. With its particle telescope, CEASE also measures the surface radiation dose that shortens the life of solar cells. Operators can use the *Surface Dose* register provided by CEASE to estimate the effect of the orbital environment on their solar cells.

2.2 Single Event Effects

Very large energy deposition events create sufficient charge in an electronic device to alter its logic state, either temporarily (bit flip) or permanently (latch-up). The results are known as Single Event Effects (SEEs). SEEs can result in corrupted data processing, commanding, and telemetry. The worst cases can cause system failures. Typically, SEEs are induced by >50 MeV proton or high energy heavy ions. The SEE hazard is greatest in the inner radiation belt. CEASE measures large energy deposition events a large volume diode with a high energy deposition threshold and returns information on the probability of encountering SEEs on orbit.

2.3 Spacecraft Charging

Dielectric charging occurs when insulating materials absorb incident electrons. Surface charge can build on dielectric materials exposed to the space environment, leading to arc discharges. These discharges, in turn, generate significant noise transients that upset or damage sensitive on-board electronics. Lower energy electrons drive the surface charging. Additionally, charge can build on dielectric materials (e.g. shielded electronics, coaxial cables) in the interior of a spacecraft. This phenomenon is known as deep dielectric charging and is caused by high energy electrons. Both types of dielectric charging are predominantly a hazard in high altitude and geosynchronous orbits.

CEASE monitors both surface and deep dielectric charging with its particle telescope. The particle telescope determines the energy spectrum of both electrons and protons, from which several parameters are deduced, including the total dose to unshielded components such as solar cells, the probability of surface dielectric charging, and the probability of deep dielectric charging.

2.4 Telemetry

CEASE supports three telemetry streams: *Engineering*, *Science* and *History*. The *Engineering* stream contains real-time warning and anomaly data, updated once per minute. *History* data contain finer resolution data, which can be used to support anomaly resolution. The *History* data are available for the preceding 72 hours in 15-minute blocks. *Science* Data packets contain proton and electron fluxes and energy spectra, radiation dose and dose rates. The *Science* Data update rate, or the *Science Data Interval*, is selected prior to instrument delivery from these options: 5, 10, 15, 20, 30 or 60 seconds. S/N 001 has an interval of 10 seconds and S/N 002 has an interval of 5 seconds.

When CEASE is powered on, data are continuously collected from the sensors and processed by digital signal processing circuitry. After the *Science Data Interval* has elapsed, CEASE formats the raw data into a *Science Data* packet. CEASE performs further processing on the *Science Data* to produce two reduced data sets, *Engineering* and *History Data*. The *Engineering Data* are summed for 60 seconds, then formatted into the *Engineering Data* Packet. The *History Data* are summed for 15 minutes and then a *History Data* packet is created. The information in the *History Data* packets is not as detailed as in the *Science* packets and is not a substitute for *Science Data*.

All data types are continuously produced in CEASE and are always available. The spacecraft may acquire any or all of the data packets, as mission requirements dictate. The

Engineering Data packet is updated once per 60 seconds by CEASE. If not retrieved by the spacecraft during this interval, the packet is overwritten with new data by CEASE at the end of the next interval. Similarly, the *Science Data* packet is updated and overwritten once per *Science Data Interval*. The History data are maintained in a 72-hour circular *History* Buffer. Every 15 minutes, CEASE transfers new History Data into the buffer, overwriting the oldest data in the buffer. To acquire *History Data*, a command is issued to CEASE that then transmits the selected data in its buffer to the spacecraft.

2.5 Hazard Registers and Warning Flags

The output of the onboard algorithms are the real-time warnings to the spacecraft of environmental hazards due to total radiation dose, radiation dose rate, surface and deep dielectric charging, and SEEs. This information is contained in eight 4-bit Hazard Registers (HR) and eight 1-bit Warning Flags (WF). The eight Hazard Registers each have 16 levels quantifying the environmental threat. These levels range from 0 to 15 (lowest to highest threat), with each Hazard Register having a lookup table. The Hazard Register levels (except for the SEE) are logarithmically spaced over a 5 decade dynamic range for LSD, HSD, LSR, HSR and SUD, and over a 4 decade range for SDC and DDC. The SEE Hazard Register is a direct count of SEE type events detected.

The specific values in the Hazard Register lookup tables are set prior to instrument fabrication to match mission requirements. In general, the Hazard Register and Fluence Flag limits will depend on the design of the spacecraft and its orbit. It is recommended that the spacecraft manufacturer discuss the mission profile with Amptek so that proper limits for Warning Flags can be determined.

The purpose of the Warning Flags (listed in Table 1) is to provide an ON/OFF hazard alert to the spacecraft. Six of the eight Warning Flags are derived from Hazard Register values. For these six flags, if a Hazard Register value exceeds a pre-set limit, the corresponding Warning Flag is set ON (1), and otherwise the Warning Flag is set OFF (0). The two additional flags are the *electron Fluence Flags*, one for electrons with $E < 250$ keV and one for $E > 250$ keV. If the integrated electron SDC or DDC fluence over the past H hours exceeds the pre-set limit T, the corresponding fluence Warning Flag is set ON (1), otherwise it is set OFF (0).

The on-board processing algorithm tracks the Warning Flag status. In order for a Warning Flag to be set, the corresponding Hazard Register or Fluence must exceed its preset limit for 3 minutes. For the *electron Fluence Flags*, this means that the fluence values must exceed the preset limits for 3 consecutive minutes. For the WTD Flag, this requires that any combination of the applicable Hazard Registers (HR_1, HR_2, or HR_5) exceeds the preset limits for 3 consecutive minutes.

Table 1 Warning Flag List

Warning Flag (Abbreviation)	Flag Number	Source Register	Trigger

Lightly Shielded Dose Rate (WLR)	0	HR_3	HR_3 > Threat Level Threshold for 3 consecutive EMIs
Heavily Shielded Dose Rate (WHR)	1	HR_4	HR_4 > Threat Level Threshold for 3 consecutive EMIs
Single Event Effect (WSE)	2	HR_6	HR_6 > Threat Level Threshold for 3 consecutive EMIs
Surface Dielectric Charging Flux (WSC)	3	HR_7	HR_7 > Threat Level Threshold for 3 consecutive EMIs
Surface Dielectric Charging Fluence (WSL)	4	—	If measured low energy electron fluence exceeds threshold for 3 consecutive EMIs
Deep Dielectric Charging Fluence (WDC)	5	HR_8	HR_8 > Threat Level Threshold for 3 consecutive EMIs
Deep Dielectric Charging Flux (WDL)	6	—	If measured high energy electron fluence exceeds threshold for 3 consecutive EMIs
Total Dose (WTD)	7	HR_1, HR_2, HR_5	HR_1, HR_2 and/or HR_5 > their specific Threat Level Threshold for 3 consecutive EMIs

The Warning Flag thresholds (0-15) can be set by ground command. A value of 15 is the default stored onboard CEASE for all Warning Flags except for the fluence flags. For the fluence flags, the fluence limit T and the value of H can be set by ground command. The value of H can be set between 1 and 24 hours in 1-hour increments. The default settings are H = 24 hours and the Fluence Flag limit = 4×10^9.

3. INSTRUMENT DELIVERIES AND INTEGRATION

CEASE S/N 002 was delivered to OSC in June 1998 for integration onto the TSX-5 spacecraft. S/N 002 was successfully mechanically and electrically integrated with the TSX-5 spacecraft. At the time of integration, Orbital Sciences Corporation (OSC) had not completed their flight processor (EIP) or their I/O board. Full functional testing of the MIL-STD-1553 interface to CEASE was accomplished using the TSX-5 Engineering EIP. This testing included checking all CEASE commands and polling the Science, Engineering and History data packets from CEASE. The only interface with the TSX-5 I/O board is the CEASE temperature monitor – this will be tested when OSC has an operational I/O board.

Delivery of CEASE S/N 001 to DERA UK for integration onto STRV-1c was accomplished in February 1999. Final testing was conducted per the DERA Experiment Acceptance Test Plan (EATP) verifying that CEASE meets the mechanical, functional, power, OBDH, and magnetic susceptibility requirements. An Acceptance Data Package, meeting the requirements of the EATP, was completed and delivered with the instrument.

Interface testing in the UK was conducted to ensure that the serial interface provided by DERA on STRV-1c has been implemented correctly. A number of items were in error on the DERA side of the interface and were corrected as a result of the testing conducted. Also, testing was conducted per the DERA Experiment Acceptance Test Plan (EATP) verifying that CEASE meets the mechanical, functional, power, OBDH, and magnetic susceptibility requirements.

4. FUNCTIONAL TESTING AND CALIBRATION

During this reporting period, a significant effort was devoted to Ground Support Equipment (GSE) software. Software to simulate the STRV-1c spacecraft interface was completed. This software is used to poll CEASE S/N 001 for data and to write these data to a file. Data from the file can then be displayed either in real-time or post-test using CEASE GSE Flight Display software. Modifications to the Flight Display software were also accomplished in this reporting period. The GSE Flight Display software is described in the Section 4.1.

4.1 Flight Display GSE Software

CEASE is designed to support several different operational strategies, depending on the mission requirements. It operates autonomously, without continuous telemetry transmission to the host spacecraft. CEASE always processes the raw data it collects from its sensors and prepares all of the data packets at the specified rates. CEASE only transmits the prepared packets upon request from spacecraft.

The Flight Display GSE software was designed to facilitate functional testing, calibration, integration with the spacecraft, and on-orbit operations. To support the various operational schemes for CEASE, the Flight Display GSE software processes and displays all types of CEASE data. A configuration file is used to tailor the displays to specific CEASE instruments.

CEASE telemetry as described in Section 2.4 must be processed by mission-specific software that correctly formats the CEASE telemetry for this Flight Display GSE software. The required format is a file with records each containing 70 bytes. Bytes 0-3 contain a time stamp. Bytes 4-5 contain the packet (i.e. record) ID. This ID is: 0 for Engineering, 1 for Science, and 2 for History. Bytes 6-69 contain the data:

Engineering	10 bytes of data & 54 bytes of zero-fill
Science	56 bytes of data and 8 bytes of zero-fill
History	52 bytes of data and 12 bytes of zero-fill

Data files can be viewed real-time or in playback. In Figure 1, the playback controls are shown in the lower right corner of the display. Alternatively, file control is available from the *Control* pulldown menu. The Flight Display GSE can also be used to process the CEASE data into individual files containing comma separated variables. This feature can be used to import CEASE data into other software for further analysis.

The software logs the receipt of all types of CEASE data, including commands issued to the instrument. The tracking functions are displayed on the Logs, Records, and Telemetry pages. Only data with proper sync and checksums are displayed by the Flight Display GSE on the Science, Engineering and History pages. Rejected data from the formatted file are displayed in an Error box on the Records page. The filename, record number, CEASE frame counter and time stamps are visible from any page. Accumulation time, if accumulate is invoked, is also always displayed.

The Warning Flags are always available to the user. The box is green if the flag has not been set. If the flag has been set, the box initially is blue with a white X in it. If the next frame still has the bit set, then the box becomes red with a white X through it. This scheme was chosen to handle the case where telemetry signals could be noisy, with bits inadvertently set in transmission rather than by CEASE.

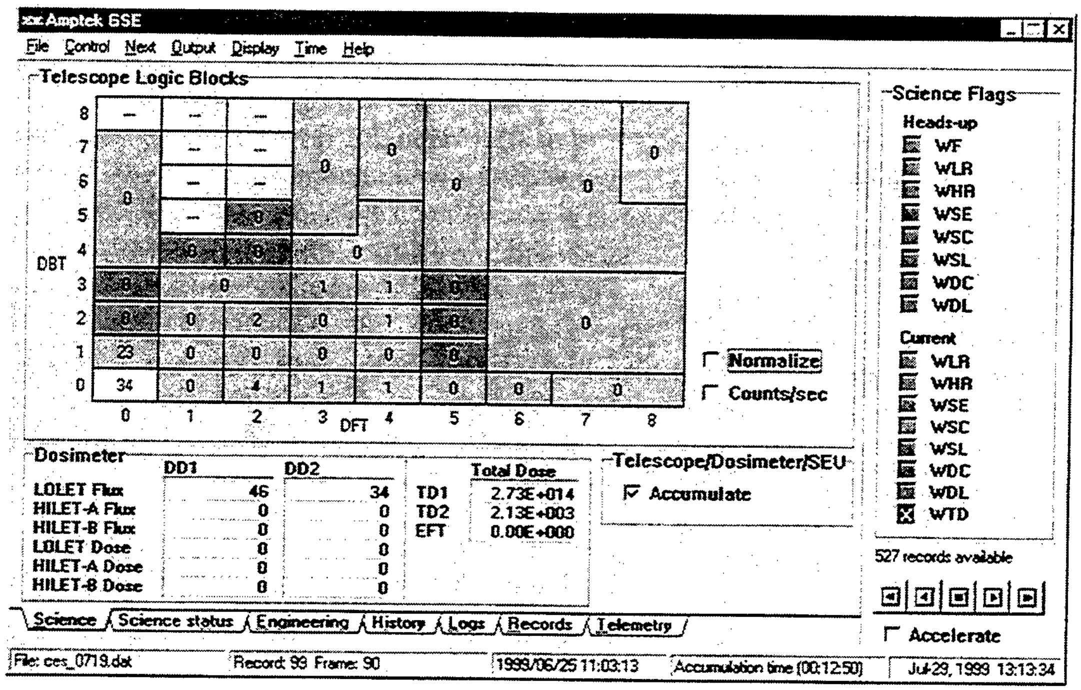

Figure 1 Flight GSE Science Display Page

Telescope Data

The data collected from the CEASE telescope are stored in 80 channels, corresponding to different energy deposition values in the front (DFT) and back (DBT) telescope detectors. Each detector has eight energy deposition thresholds set in the readout electronics with thresholds TFA through TFH for DFT, and TBA through TBH for DBT. The thresholds separate the range of the possible energy depositions by incident particles into 80 regions called Logic Boxes (LB) Selected LBs are contained in the CEASE Science Data Packet.

The critical LBs are updated at the rate of the Science Data Interval. LBs that are used primarily for noise checks are subcommutated in the telemetry and their update rate is once per 32 major frames. Those boxes are outlined in the telescope portion of the display on the Science Page (Figure 1).

On this page, the boxes are color coded for update rate - blue for SDI update rate and green for subcommutated data. The value in yellow box in the lower left corner is the sum of the telescope counts updated at the SDI rate. This value is not part of the downlinked telemetry, but is calculated by the GSE software. The user has the option to view the counts in the LBs normalized to this calculated total. Also, the data can be displayed as a count rate, by selecting the counts per second option. *Normalize* and *Counts/sec* only apply to telescope data. *Accumulate* applies to the Telescope total and the LBs updated at the SDI rate.

The particle telescope data are also used to determine the surface dose to unshielded components (Section 2.1). The critical parameter is the Effective 1 MeV fluence. This value is displayed in the *EFT* box. This value is in the 32-deep subcommutated channel in the Science packet and is updated only when all four bytes are received.

Dosimeter Data

The CEASE has two dosimeter detectors, DD1 and DD2. DD1 is located behind 0.08 inches of aluminum (Al) shielding and DD2 is behind 0.25 inches of Al shielding. Pulse heights from each dosimeter are stored in two 256 channel spectra – LOLET and HILET. The LOLET spectrum in CEASE covers the particle energy deposition range from 50 keV to 850 keV. The HILET spectrum covers 850 keV to 10 MeV.

Note that the generally recognized LOLET range is from 50 keV to 1 MeV and the HILET lower limit is 1 MeV. In CEASE S/N 001, flight software shifts the data such that the data downlinked in the Science telemetry for LOLET flux and dose corresponds to this energy range and the HILET lower limit is 1 MeV. This flight software change was not implemented in CEASE S/N 002; its LOLET flux and dose correspond to the range of 50 keV to 850 keV and its HILET lower limit is 850 keV.

The DD1 and DD2 LOLET and HILET fluxes and doses displayed by the Flight GSE software correspond to the energy ranges in the flight instrument. These data are duty cycle corrected in the Flight GSE processing. The data displayed are in counts, not rads. The flux and dose values can be Accumulated.

Total Doses from DD1 and DD2 are displayed in TD1 and TD2, respectively. These are included in the 32-deep subcommutated channel in the Science packet and are updated accordingly. These total dose values are not affected when *Accumulate* is selected.

SEE Data

The SEE detector in both CEASE S/N 001 and S/N 002 is a PIN photodiode identical to that used for the dosimeters. The difference between the SEU detector and the dosimeters is in the processing of events measured by the detectors. The output signal from the SEU detector is connected to an electronics chain with a low gain amplifier and a high level threshold. In order for the signal to exceed the threshold, the energy deposition in the SEU detector must be greater than ~50 MeV. There is also a low level threshold setting that is ~1 MeV and is used to calibrate the SEU detector. The ~50 MeV threshold is the NORMAL threshold and the ~1 MeV threshold is the LOW threshold. The SEE data are available on the Science Status page (Figure 2).

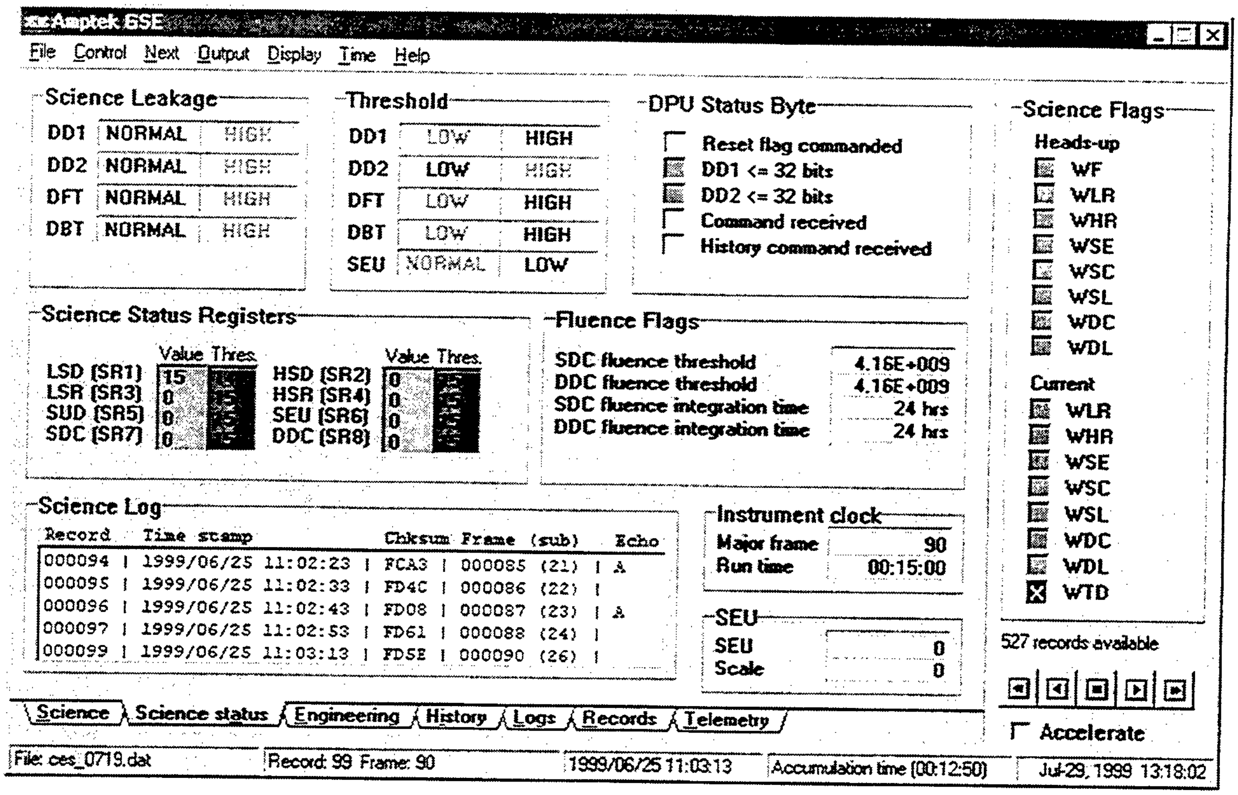

Figure 2 Flight GSE Science Status Page

Instrument housekeeping and status are maintained on the Science Status Page. The detector leakage current monitors and hardware thresholds are displayed. Command receipt and processing, detected dosimeter noise, and watchdog timer resets are viewed in the *DPU Status Byte* section. The Hazard Register and the Warning Flag register thresholds are in the *Science Status Registers Value and Thres.* section. Instrument frame counter and time since power-on are shown in the *Instrument Clock* area.

4.2 Flight Code Testing

In addition to the characterization of the CEASE detection elements, the performance of the CEASE flight code has been tested. The algorithms described in Scientific Report No. 1, *PL-TR-97-2105*, were implemented in the CEASE flight code. Using both pulsers and radioactive sources, each algorithm for each Status Register has been tested as were the settings for toggling the Warning Flags ON and OFF. Testing included verification of appropriate dead time corrections at high count rates. The entire CEASE command set was also verified. To facilitate additional benchtop testing and particle beam calibration as required, a capability was added to the flight software allowing the user to switch between the flight processing and the calibration data processing scheme.

Interface testing was conducted for S/N 001 and S/N 002. For S/N 001, the final flight serial interface as specified by the spacecraft integrator (DERA) was implemented. This interface has been tested with the spacecraft in the UK via spacecraft GSE, prior to CEASE integration onto the spacecraft. For S/N 002, the required MIL-STD-1553B interface was tested with the spacecraft prior to mechanical integration onto the spacecraft. These tests also verified that all types of CEASE data (Science, Engineering, and History) contain the correct information, are uncorrupted, and are produced at the appropriate rates.

4.3 Environmental Testing

Random vibration testing of S/N 001 was successfully conducted to the Ariane 5 qualification levels for acceptance time duration. Prior to this testing, final staking and cleaning of the unit was accomplished. The test specifications for all three axes are given in Table 2.

Table 2 S/N 001 Random Vibration Test Levels

	Frequency Range (Hz)	Power Spectral Density (g^2/Hz)	RMS Value (g)	Test Duration (sec)
Acceptance Level	20-50	+6 dB/Oct, 0.18 g^2/Hz at 50 Hz	16.4	60
	50-500	0.18 g^2/Hz		
	500-700	-3 dB/Oct		
	700-2000	0.12 g^2/Hz		

Thermal vacuum cycling was done to verify CEASE S/N 001 functionality during 5 thermal cycles, ranging from -20°C to +40°C, while under vacuum. These tests were conducted with a stimulus source cover on the instrument. The test procedures are documented in *CES-075, Thermal Cycling Test Procedures for the Compact Environment Anomaly Sensor (CEASE) Instrument.*

The S/N 001 CPT was executed at the beginning and the end of the thermal cycling at room temperature and at each temperature limit at +28 Volts for each of the 5 thermal cycles. The data were examined for significant drift in performance and for failure of CEASE to execute commands. The success criterion will be error-free completion of 5 thermal cycles. Additionally, Hot and Cold starts were performed at the specified spacecraft power bus extremes, +24 Volts and +32 Volts. CEASE S/N 001 successfully completed thermal vacuum testing.

As specified in Scientific Report No. 2, CEASE S/N 001 successfully completed EMI/EMC testing in accordance with MIL-STD-461.